The Evolution of Life Into the Far Future

The universe may be open, closed, or flat – the open or closed refer to the local geometry of the universe. In the ABSENCE of a cosmological constant:

- Open universe – has a saddle-shaped geometry and will expand forever.
- Closed universe – has a convex geometry, is compact (usually some analogue of a sphere), and will collapse; that is, it has a finite lifetime.
- Flat universe – has a flat (Euclidean) geometry everywhere, and will continue to expand forever.

Recent observations of supernova explosions have lent strength to the theory that the universe is not only FLAT, but due to the presence of a cosmological constant – a negative energy expansive push – the rate of expansion of the universe will increase as time goes forward.

If we live in a universe that will **expand onwards forever** (as current observations tend to support), then life, in order to survive forever, must address certain issues[1]

1. **The death of all stars** – even after the engines for starbirth (dead after, at most, 10^{12} years or so) – by 10^{14} years.

2. **Planets will be detached from stars** – 10^{15} years.

[1] Taken from F. J. Dyson, "Time Without End: Biology in an Open Universe," Reviews of Modern Physics 51, 447 (1979).

3. **Stars will be detached from galaxies, and the rest of the matter will collapse into central galactic black holes** – 10^{18} - 10^{19} years.

4. **Evaporation of black holes** – for 1 solar mass holes, is 10^{54} years. For a galactic mass black hole, it is 10^{100} years.
   ...In the last second of its existence, it [black hole] will emit about 10^{24} Joules of high-energy radiation. The cold expanding universe will be illuminated by occasional fireworks for a long time[1].

5. **Matter is liquid at all temperatures** – on time scales of 10^{56} years, everything that is made of solid materials will flow like a liquid (rocks, asteroids, grains of dust, Voyager spacecraft if it is still in one piece).

6. **The decay of everything into iron** – the fusion of all elements lighter than iron and the fission (radioactive decay) of elements heavier than iron into iron (the most stable element) takes place over **10^{1500} years**. This is the future evolution of everything into iron balls, and all remaining white dwarfs into iron white dwarfs.

7. **The collapse of iron stars into neutron stars** – a white dwarf made of iron could release gravitational energy by collapsing into a neutron star, but it is EXTREMELY improbable. This will take place over **$10^{10^{\wedge(76)}}$** years (that is, a 1 followed by 10^{76} zeroes!).

8. **OR collapse of ordinary matter into black holes** – if all ordinary matter can collapse into black holes, then the time over which this occurs is $\mathbf{10^{10\text{^}(26)}}$ (that is, a 1 followed by 10^{26} zeroes!).

Both proponents of intelligent life – those in a closed, finite universe, and those in an open infinite universe – take the position that only a *subjective time* is important. That is, rather than using absolute time as a measure, they use a finite subjective time.

- For a closed universe, one expects that life must somehow either survive through the inevitable collapse OR "live forever," by operating at an asymptotically faster rate.

- For a future universe that expands faster as time goes on, the operating temperature and the processing speeds must slow down as the universe cools if the life wishes to "live forever."

    - Life has available to it only a finite amount of information to survive for an infinite amount of time.

    - For any machine, it must operate at a temperature above the Universe's background temperature.

    - Other important points – Dyson, for example, has proposed that life would hibernate for longer periods of time as time goes forward.

- For **digital kinds** of life, where information is in "ones" and "zeroes" (like modern computers, and maybe our brain at its basic levels), if the temperature drops below the threshold energy for storing energy, then computer is "dead"

  $E_{state} > k_B T$

- For **analog** life (such as a "black cloud"), it is possible that life can continue on forever EVEN with a finite amount of energy – because as the universe cools, the cloud cools and expands, BUT the information increases at such a rate that this is possible(?)
  - Some examples of analog – LP player, knobs on some stereos, slide rules, thermometers.
  - Also, may be possible that a future analog computer may be superior to a digital computer that we may make.
  - If the cloud or other analog computer consists of elements that THEMSELVES grow larger as the universe expands and cools, then perhaps life can exist forever.

- Perhaps insurmountable problems might arise from the fact that the Universe is expanding, and thus is believed to have a finite temperature (10^{-29} K) associated with this expansion – may have issues with the black cloud also.

Weak Anthropic Principle and the Doomsday Argument – Stuff we Cannot Predict and Cannot Yet Observe

The Weak Anthropic Principle: We observe the universe and its specific properties (such as total mass, strength of gravity, etc.) because the nature and age of the universe allowed for our evolution and existence.

- It is unlikely that we would have evolved before stars were formed or after the processes of stellar fusion have disappeared.
- Perhaps other, to us incomprehensible, types of life existed before the existence of stars or will exist into the far reaches of the universe.
- This is a very general type of "selection effect." Others include
    - We have eyes tuned to visible light because our atmosphere is transparent to it.
    - We use radio telescopes in large part because the atmosphere and surrounding space is transparent to it.
    - We evolve to be tolerant of oxygen because the air is full of it.
- Essentially stating, perhaps it is unspecial on the way the universe is, because this is the only (or one of the only) ways in which something exactly like us could come into existence.

Doomsday Argument

It was first proposed by Carter[2] and then reproduced in the science community by Gott[3].

Essence of the argument – *assuming that it is equally "likely" in a sense for anyone to be born at a given order in our history, then given the total number of people born today, and our current rates of birth, it is pretty likely that we will die soon (within a few centuries).*

Assumptions in making the Doomsday Argument:

1. **The Copernican Principle** – each individual person, or even our species, or even our planet, are not especially unique or "special" in the Universe.
2. **Lack of information** – we can make no assumptions about the future. We have no access to an actuarial table that gives us the probability of our civilization's surviving. It is even possible that within the next generation or two our own current actuarial tables (describing mortality rates in people) will be rendered hopelessly obsolete.

So that GIVEN WHAT WE DON'T KNOW, we can make a "null" hypothesis about our future history.

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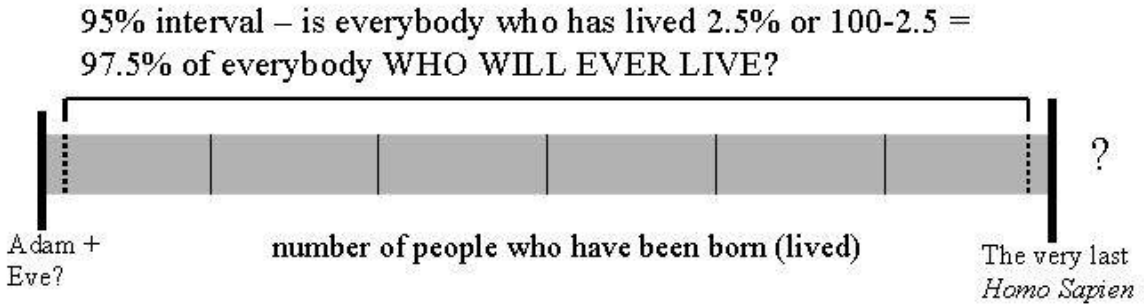
[2] B. Carter, *Philosophical Transactions of the Royal Society A* **310**, 347-363 (1983).
[3] J. R. Gott, "Implications of the Copernican Principle for Our Future Prospects," *Nature* **363**, 315-319 (1993).

There have been 100 billion people born throughout human history. Given this information alone, what is the "most likely" number of people that **WILL HAVE BEEN BORN** for humanity, *considering that it is equally likely to be born at any order*?

- This is defined as "most likely" range, or the 95% confidence interval,



  of people who will ever have been born.
- By 95%, we mean that are we the first 2.5% of people to live or the first 97.5% of people to have lived (that is, there is only 2.5% of the total human population left).
- With these numbers, there are most likely $\frac{40}{39}N_{present} < N_{total} < 40N_{present}$ people that will have lived, so then there will be most likely: 102.6 billion < N_{total}< 4 trillion
- Even if population stabilized at 7.5 billion in 10 years or so (when 103 billion people will have been born), and the average lifetime was 75 years:
  - The birth rate, to stabilize at 7.5 billion with a life expectancy of 75 years, is 7.5 billion/75 = 100 million births/year.
  - With that result, we would then expect the human race to live for T ~ 4000 years at most, long but much smaller than geological timescales.

Essentially, we are saying that it is much more likely that we are one of the last people (in human history) rather than one of the first – otherwise, it would be MUCH MORE LIKELY that we would be a person born during the stage of "galactic colonization" (when the numbers of people would be on the order of $10^{18} – 10^{24}$).

Of course, this is a statement of *likelihood*. It does not give any answers.

- It was intrinsically unlikely that a band of a few thousand people in Africa would go on to colonize the world, and form a civilization of billions of people.
- It was very unlikely that the United States would, from its birth, go onto become such a powerful nation. Repeat the argument for any great civilization of the past.
- The current lifetime of our civilization and species << geological time scales, so our predicted civilization lifetimes << geological time scales.
- Could be easily disproven by the existence of a large, old civilization – means that the chance that any intelligent being on this planet being born is relatively unlikely over the chance that the intelligent being is born anywhere.
- Absence of evidence does not equal evidence of absence (just makes it less and less likely as time goes on).
- Intelligence, like other adaptations, are rarely used to their maximum utility – a sunfish can lay 30 million eggs, but only a few will survive, for example.